



# MONITORING REPORT

A 12-month assessment of ecological recovery on  
Resting Reef's memorial reef pilot in North Bali

RestingReef



Figure 1: Aura and Louise in Tianyar

# A NOTE FROM THE FOUNDERS

This first Resting Reef Impact Report is a milestone we're incredibly proud of. It reaffirms our commitment to building sustainable practices and placing a science-based approach at the heart of what we do.

We're proud of our team for making this possible, and we look forward to witnessing even more restoration unfold while strengthening our commitment to the people and the planet we serve along the way.

This is only the beginning!

*Louise Laura*





Figure 2: Co-founder, Aura, preparing to descend for a monitoring dive

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# INTRODUCTION

Resting Reef's pilot was established to evaluate how well newly designed memorial reef structures support the restoration of marine life on degraded coral reefs in North East Bali. The pilot also aimed to test the durability of Resting Reef's material formula, including a set which incorporated cremated ashes.

The pilot sites were located in two neighbouring coastal villages, both in North East Bali. In these locations, local craftsmen built and placed the structures underwater at depths of approximately 5-6m in Tianyar and 4-5m in Tulamben.

## PILOT LOCATIONS:

TIANYAR

TULAMBEN



Figure 3: Drone shot of Tianyar beach



Figure 4: Preparation for Resting Reef deployment

# TIANYAR

10 Resting Reef units placed

Within the house reef at North Bali Reef Conservation, a local community initiative led by Pak Ketut De Sujana Mahartana.

# TULAMBEN

8 Resting Reef units placed

Part of a local coral restoration initiative led by Pak Nyoman Degeng. The primary purpose of the pilot in Tulamben was to assess the durability and ecological performance of structures which incorporated cremated ashes.

# RESEARCH QUESTIONS

Monitoring the ecological development of these structures was crucial for ensuring that Resting Reef units were durable and ecologically beneficial. This is key in helping the time to refine the design and materials, providing evidence to future clients, partners, and regulators of the effectiveness of the memorial reefs.

Three central research questions guided this work:

1. To what extent can the memorial reefs enhance habitats, compared to nearby degraded reef control sites?
2. Do ash-integrated units remain durable underwater, and does this affect ecological recruitment compared to nearby degraded reef control sites?
3. Which aspects of the Resting Reef design best support biodiversity?



Figure 5: Resting Reef placement by local SCUBA team

# METHODS


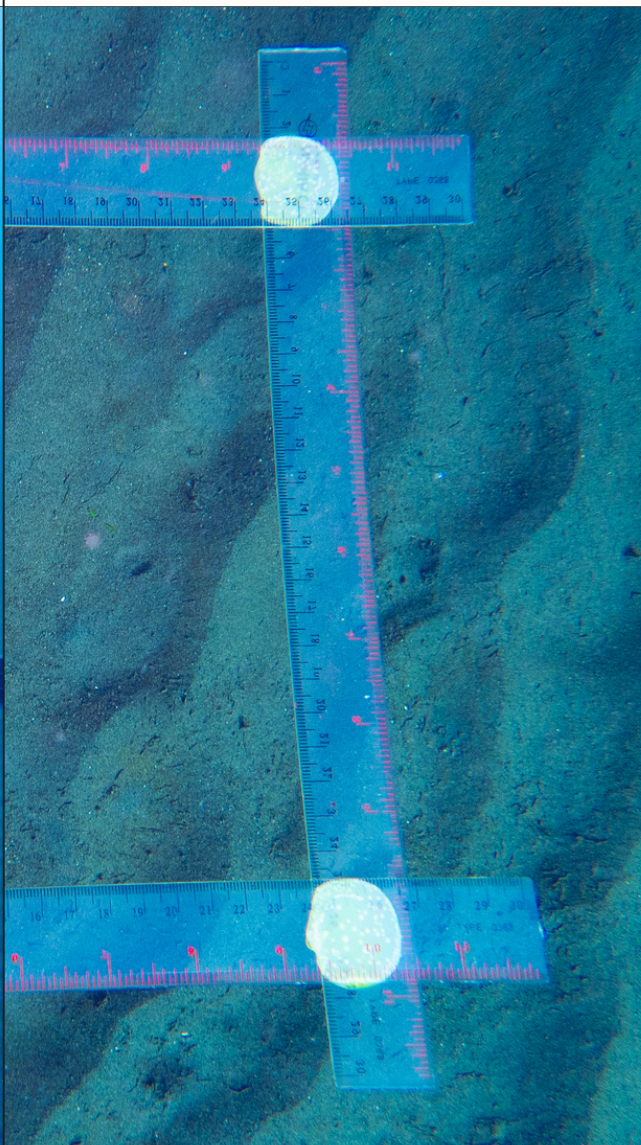


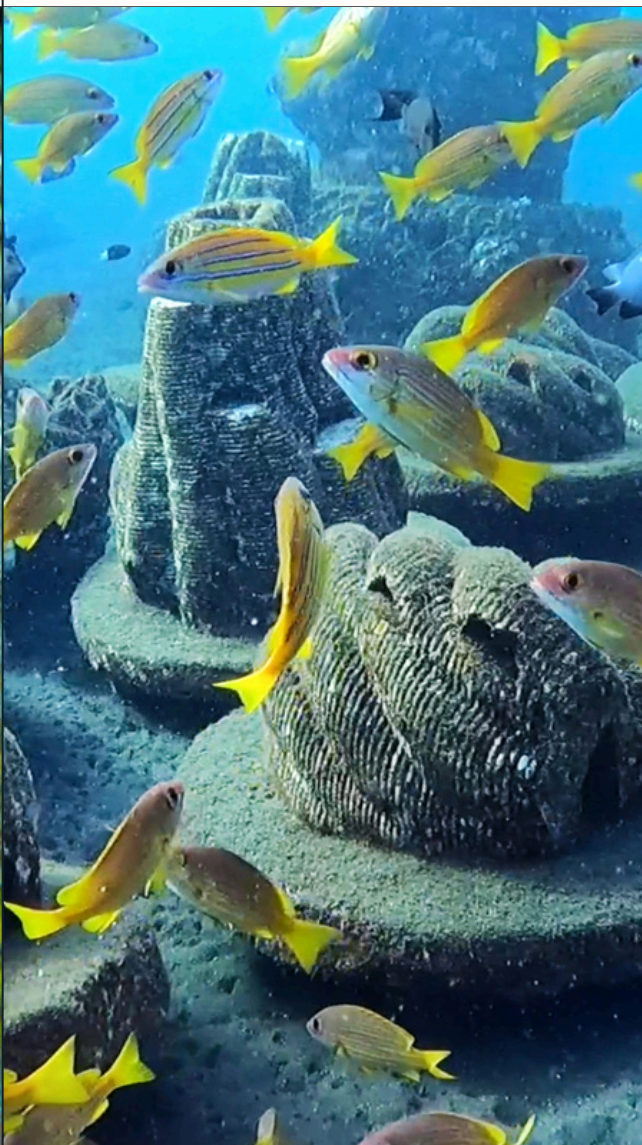

STUDY SITES AND MONITORING SCHEDULE	CONTROL SITE	MONITORING APPROACHES	BENTHIC SURVEYS	FISH SURVEYS	STATISTICAL ANALYSES
					



Figure 6: Location of Resting Reef's two pilot sites in Tianyar Village and Tulamben Village in Bali, Indonesia.

# STUDY SITES AND MONITORING SCHEDULE

Monitoring was carried out at both pilot sites (Figure 6) over the first year following deployment of the Resting Reef units.

In Tianyar, the structures were deployed in July 2024 and monitored at 4, 8, and 12-month intervals after deployment. In Tulamben, structures were deployed in August 2024 and monitored at 6 and 12 months. This monitoring design reflected the slightly different research focus at each site; the priority for Tianyar was to assess ecological performance, whereas the pilot in Tulamben placed a stronger emphasis on testing the durability of structures that incorporated cremated ash into the formula.

# CONTROL SITE

At both locations, a nearby degraded sand-flat reef, approximately 200m from the memorial reefs, served as the control area. At both, local knowledge confirmed that these sites were formerly healthy coral reefs, but had been destroyed decades earlier through anchoring, coral harvesting, and destructive fishing practices. At the time of monitoring, the control sites consisted mostly of a sand bottom with limited/no hard substrate availability and sparse biological communities. It therefore represented the likely condition of the habitat in the absence of artificial reef structures, making it a suitable basis for comparison with the Resting Reef units.



Figure 7: Resting Reef control site in Tianyar

# MONITORING APPROACHES

Ecological monitoring followed the same dual-approach commonly used in marine restoration assessments, separating the ecological community into:

1. Benthic communities (organisms attached to the reef structures, such as corals, algae, and sponges).
2. Mobile fauna (mostly fish, and the occasional invertebrate).

These methods were based on pre-established protocols, including Boakes et al. (2023, 2025) for fish abundance metrics, and Leujak and Ormond (2007) for benthic surveying methods.

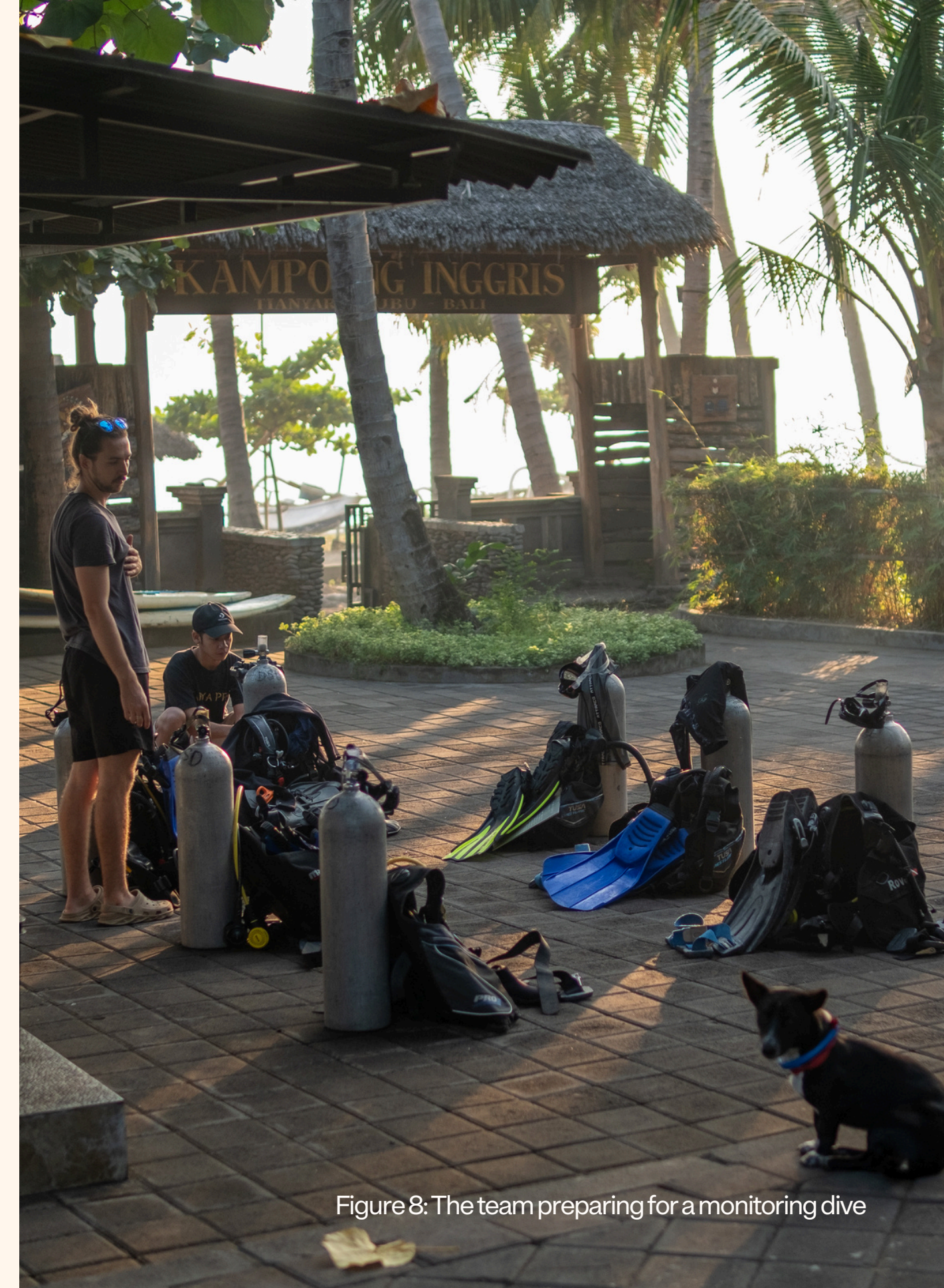


Figure 8: The team preparing for a monitoring dive



Figure 9: Photoquadrate example

# BENTHIC SURVEYS

Benthic colonisation on the Resting Reef units was quantified using photo-quadrate sampling, a standard method for describing benthic community structure on coral reefs. Following Leujak and Ormond (2007), 20 × 20 cm quadrats (example shown in figure 9) were placed onto the Resting Reef units and photographed using an Olympus TG-6 digital camera. Care was taken to remove bias by randomly selecting specific parts of the units to sample.

For each monitoring period, 30 photo-quadrats were taken of the Resting Reef units, and 30 were taken at the nearby control site. This resulted in 30 quadrats per time-point on the artificial structures in Tianyar (three time-points), 30 per time-point in Tulamben (two time-points), and a single set of 30 quadrats at the control site. Then, the percentage cover of each benthic category was calculated, using Coral Point Count software with Excel extensions (CPCe).

# BENTHIC SURVEYS

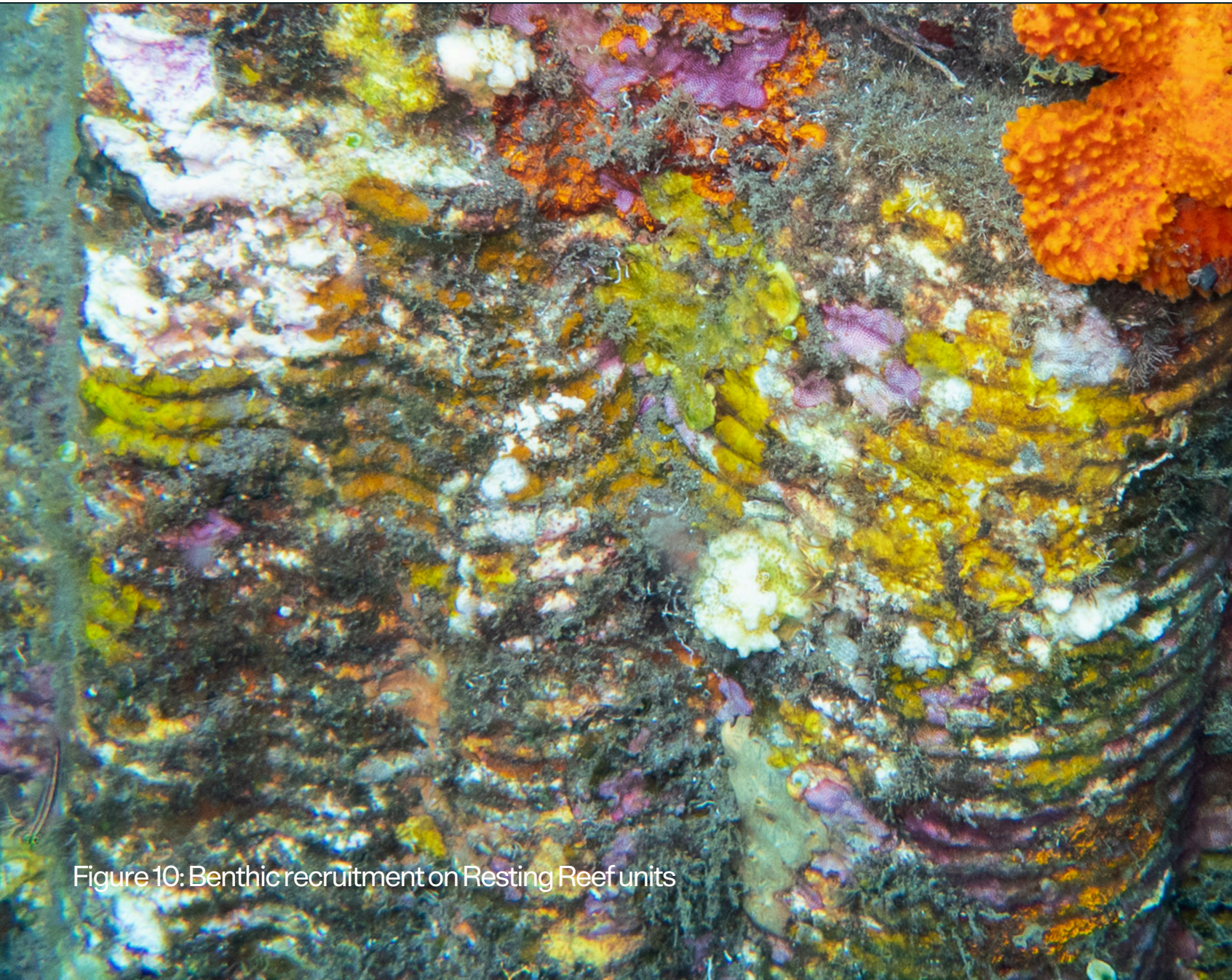


Figure 10: Benthic recruitment on Resting Reef units

The following benthic categories were recorded:

EMPTY SPACE

TURF ALGAE

HARD CORALS

HYDROIDS

CORALLINE ALGAE

ASCIDIANS

SPONGES

ECHINODERMS

MACROALGAE

SAND

# FISH SURVEYS

Mobile fauna, primarily fish, were monitored using Remote Underwater Video (RUV), following the methods of Boakes et al. (2025). This non-destructive method allowed fish communities to be sampled without the presence of a diver, reducing the risk of disturbance.

Recordings were only taken under calm conditions with underwater visibility of at least 15 m. For each sample, the camera recorded for 25 minutes, with the first 5 minutes removed (as it was considered a "settlement period" to allow the fish to resume natural behaviour after deployment of the camera) and the remaining 20 minutes used for analysis.



Figure 11: Deployment of RUV recording equipment



Figure 12: Fish surveying in Tulamben

# FISH SURVEYS

At each monitoring period, three replicate videos were recorded for each habitat type (Resting Reef and control). The camera was placed approximately 1 m away from the memorial reefs and, although its exact position varied slightly each time, all of the Resting Reef units were captured in each frame. Fish were identified to species level using regional identification guides. As a relative measure of abundance, the maximum number of individuals of each species seen in any single frame (MaxN) during the 20-minute analysis period was recorded, following Whitmarsh et al. (2017).

At the Tianyar control site, unusually high counts of *Heteroconger hassi* (spotted garden eels) were recorded in some samples. This species forms dense colonies in sandy areas, and its visibility fluctuates substantially because individuals retreat into burrows in response to changes in current, disturbance, or light, creating short-term spikes in observed abundance. As these fluctuations are unrelated to reef-associated fish community structure and would artificially inflate fish abundance at the control site, all *H. hassi* observations were removed prior to calculating fish abundance, richness, and multivariate metrics. This ensured that comparisons between restoration and control sites better reflected true reef-associated assemblages.

# STATISTICAL ANALYSES

The data were analysed in R, a computer program used to analyse scientific data. Benthic cover measurements were organised for comparison between the Resting Reef sites and control sites. Then, Shannon diversity ( $H'$ ) was calculated to measure how many different species were present and how evenly they were distributed. To compare how similar or different the communities were, a method called Bray–Curtis dissimilarity was used. Then, a PERMANOVA test was run to check whether the groups were statistically different.

Benthic cover data was also compared between the Tianyar and Tulamben Resting Reef sites at the 12-month monitoring interval to assess the differences between the two locations and whether the structures which incorporated ash (in Tulamben) influenced benthic recruitment. Hard coral cover values were extracted, and absolute and percentage differences calculated.



Figure 13: Screenshot from RUV video recording analysed to estimate fish diversity and abundance



Figure 14: Moon wrasse (*Thalassoma lunare*) seeking refuge inside purpose built tunnel inside a Resting Reef memorial reef.

For the fish communities, measurements included species richness (how many species were present) and total abundance (the total number of fish counted across all species) for each sample.

Then, a two-way ANOVA was used to test whether richness and abundance changed based on Location (Tianyar or Tulamben), Treatment (Resting Reef or control), or the combination of both factors. Overall fish community structure was examined using Bray–Curtis dissimilarity and a PERMANOVA test, with Location and Treatment as the main variables.

# RESULTS

FISH SURVEYING RESULTS



BENTHIC SURVEYING RESULTS



# FISH SURVEYING RESULTS

Resting Reef units supported dramatically richer and more abundant fish communities than the nearby degraded control sites.

Compared with only 6 species at the control site, in Tianyar:

THE RESTING REEF SITE SUPPORTED 102 FISH SPECIES

Compared with 16 at the control, in Tulamben:

THE RESTING REEF SITE SUPPORTED 67 SPECIES

Figure 16 displayed the fish monitoring results drawn from the pilot study, in terms of species richness and total abundance at both Resting Reef locations and adjacent control sites.

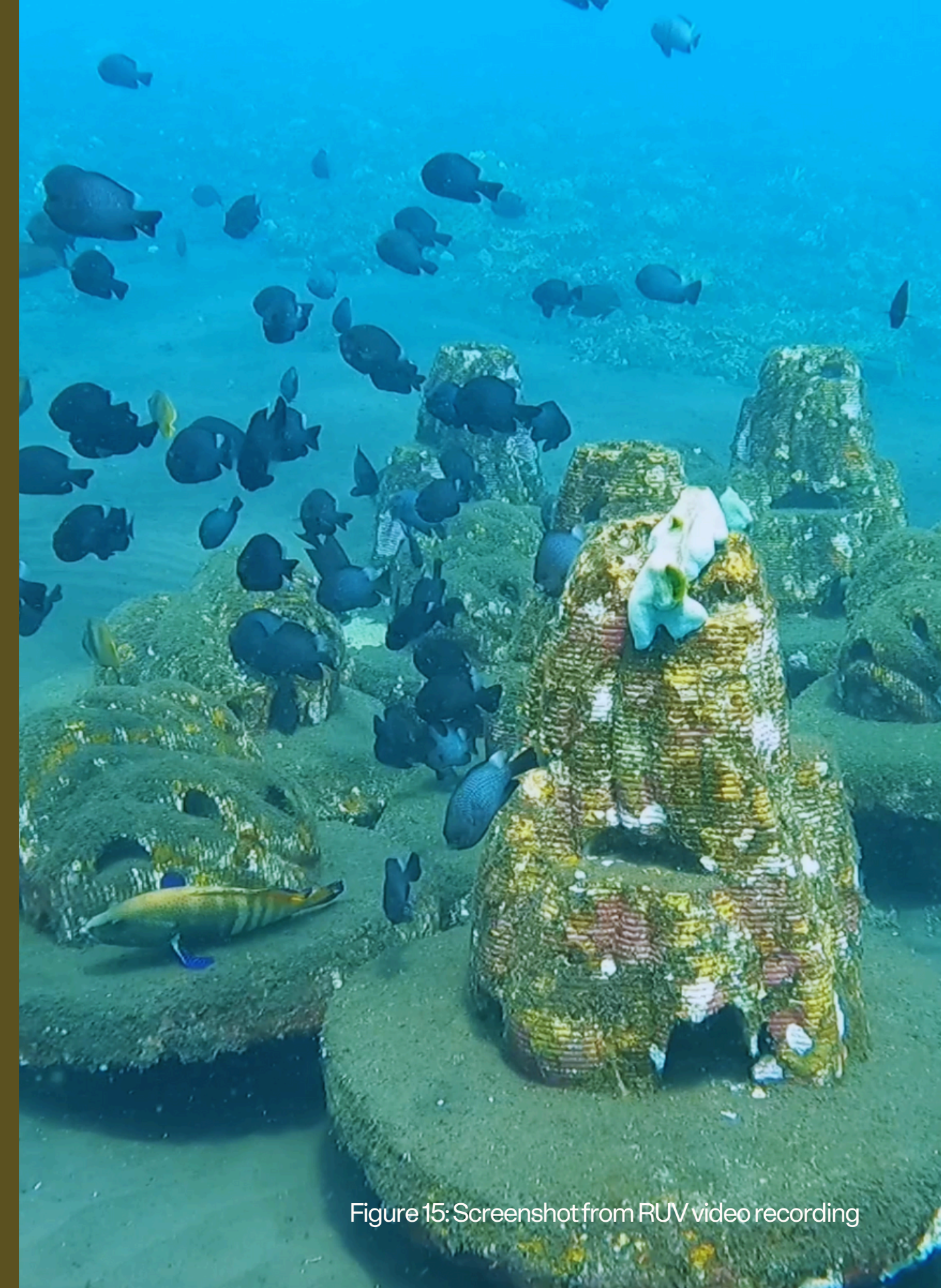


Figure 15: Screenshot from RUV video recording

# FISH SURVEYING RESULTS

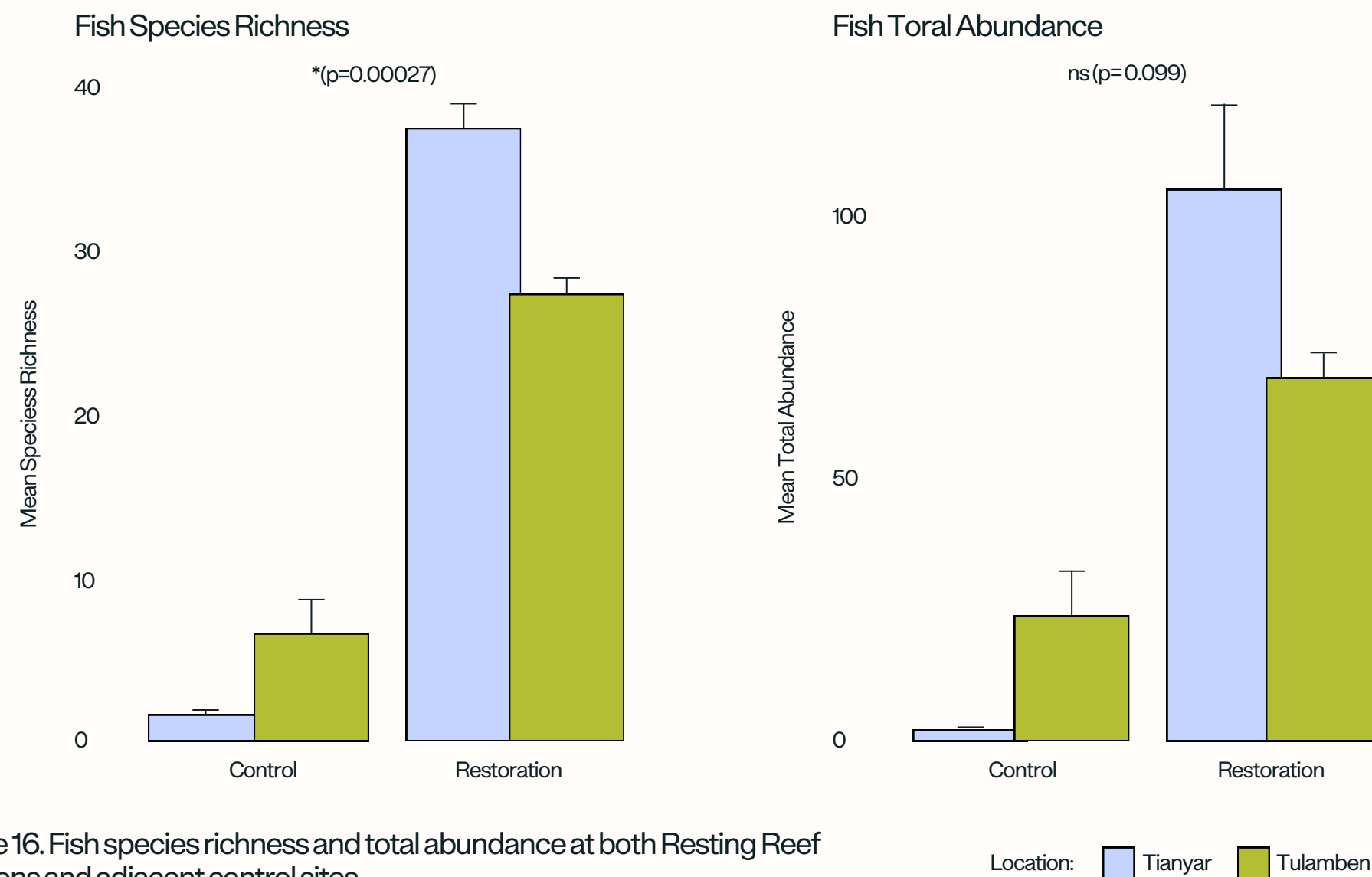


Figure 16. Fish species richness and total abundance at both Resting Reef locations and adjacent control sites.

Statistical analyses also confirmed these differences. Species richness and total abundance were both significantly higher at Resting Reef sites than at control sites ( $p < 0.001$ ). These restored habitats functioned as ecological hotspots, rapidly attracting diverse fish assemblages within a year of deployment.

Fish community composition also differed strongly between the Resting Reef and the control habitats. PERMANOVA results indicated clear separation in fish assemblages between treatments ( $F = 4.47, p = 0.001, R^2 = 0.44$ ), demonstrating that restoration is not only increasing the number of fish, but also changing community structure towards more complex reef-like assemblages.



Figure 17: Two species of schooling snapper fish on Resting Reefs in Tianyar

Among the two locations, the Tianyar Resting Reef site showed exceptional recovery success, hosting the highest richness and abundance overall. This fast recovery indicated that local environmental conditions in Tianyar made it especially suitable for fish colonisation, showing strong potential for Resting Reef units to support biodiversity in this area.

# BENTHIC SURVEYING RESULTS

Resting Reef structures developed significantly more diverse benthic communities than the control sites over the 12-month monitoring period. From the Shannon diversity results, it was found that, indicating rapid development of more complex benthic communities.

THE RESTING REEF UNITS ( $H' = 1.40$ ) HAD ON AVERAGE ALMOST EIGHT TIMES HIGHER DIVERSITY THAN IN THE CONTROL AREA ( $H' = 0.18$ )



Figure 18: Deployment of new Resting Reef memorial reefs in Tulamben.

# BENTHIC SURVEYING RESULTS



Figure 19: Moon wrasse (*Thalassoma lunare*) grazing on benthic organisms growing on a Resting Reef.

Multivariate analysis confirmed strong differences in benthic community composition between Resting Reef and control sites. PERMANOVA results showed a highly significant difference in assemblages among sites, habitat types, and monitoring periods ( $F = 28.86$ ,  $p = 0.03$ ,  $R^2 = 0.99$ ). This suggested substantial structural changes and clear ecological colonisation on the Resting Reefs. In contrast, the control reef remained dominated by sand and turf algae, with negligible coral or benthic cover, and very limited structural complexity.

# RESULTS

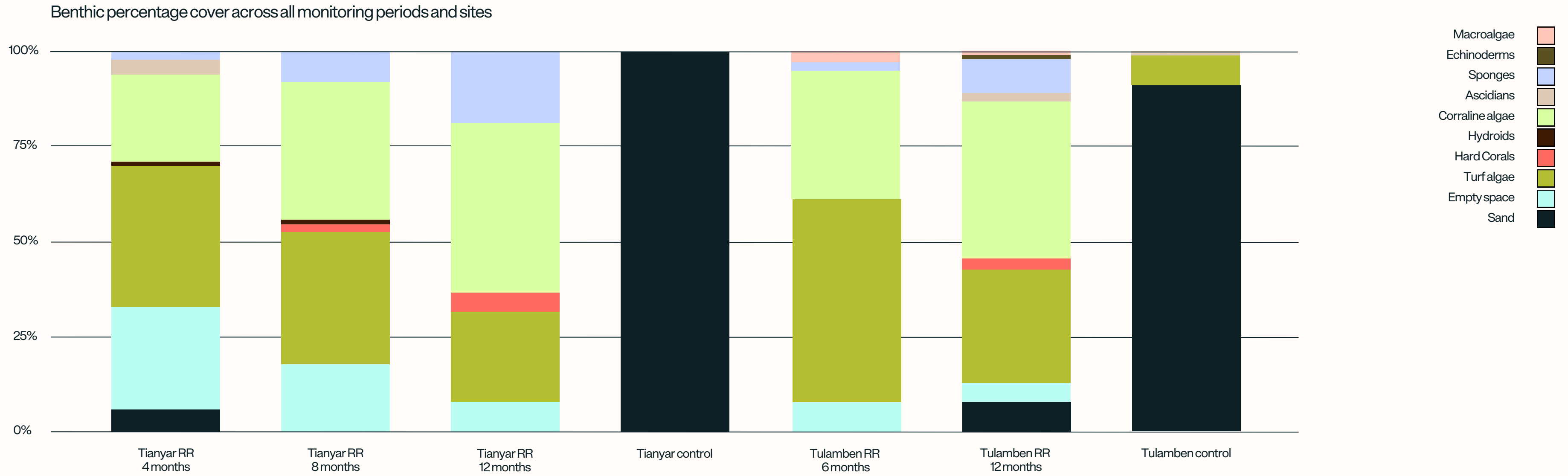


Figure 20: Benthic percentage cover across all monitoring periods and sites



Figure 21: Hard coral cover (amongst other benthos) on a Resting Reef

Two key benthic groups - hard corals and coralline algae - showed particularly strong increases through time, as shown by Figure 20. At both Resting Reef pilot locations,

Hard coral cover rose from zero to around 4–5% within a year.

Coralline algae expanded to dominate up to 45% of benthic cover on some units, providing an important stabilising layer that helps bind the substrate and create favourable conditions for ongoing coral recruitment

Comparisons between Tianyar and Tulamben after 12 months highlighted that:

Tianyar benthos was dominated by:

CORALLINE ALGAE (45.2%)

TURF ALGAE (23.7%)

SPONGES (18.9%)

EMPTY SPACE (7.7%)

HARD CORALS (4.7%)

Tulamben benthos was dominated by:

CORALLINE ALGAE (41.6%)

TURF ALGAE (30.1%)

SPONGES (8.63%),

EMPTY SPACE (5.13%)

HARD CORALS (2.9%)



Figure 22: Tunicate (*Didemnum molle*) growing on a Resting Reef.

# RESULTS

Hard Coral Cover at 12 Months, Tianyar vs Tulamben

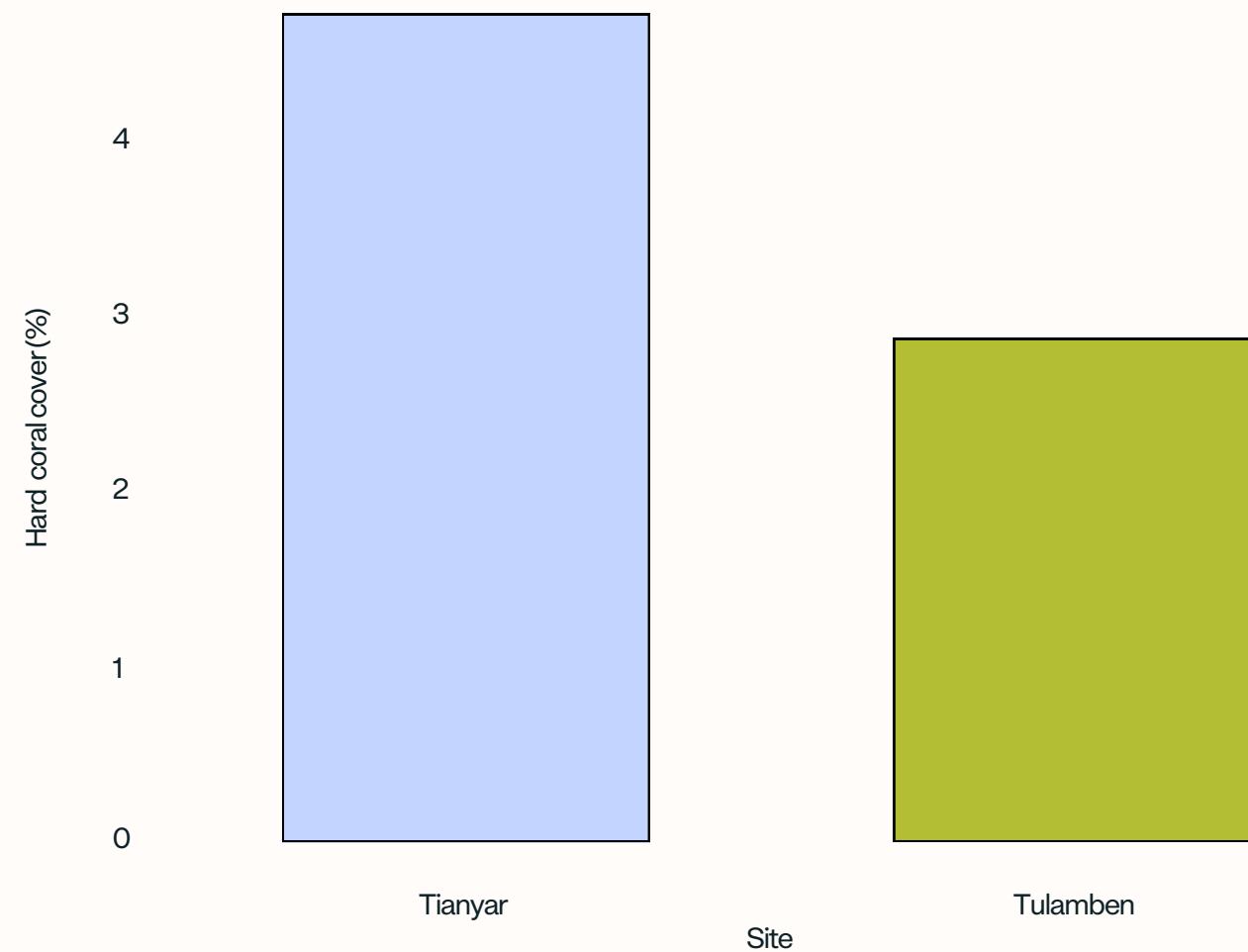


Figure 23: Percentage hard coral cover (%) on Resting Reefs after 1 year in Tianyar and Tulamben

As shown by the figure, hard coral cover was higher in Tianyar (4.7%) compared with Tulamben (2.9%), representing a 39% lower hard-coral cover at Tulamben.

# SUMMARY OF RESULTS

## 1. HUGE INCREASE IN SHANNON BENTHIC DIVERSITY

Shannon diversity results showed the Resting Reef units exhibited almost

# 8x

higher benthic diversity values than the control areas, indicating a rapid development of more complex benthic communities over the 12-month period.

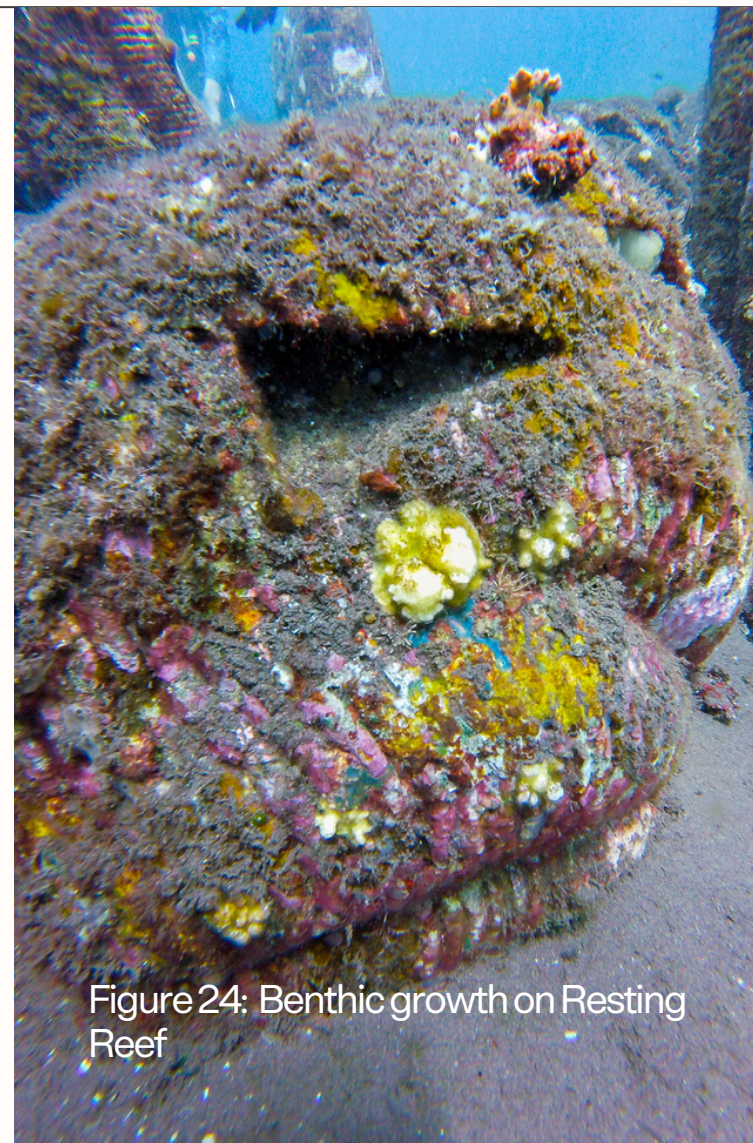


Figure 24: Benthic growth on Resting Reef

## 2. BENTHIC COVER WAS SIGNIFICANTLY HIGHER ON RESTING REEFS

Multivariate analysis showed clear differences in benthic communities between restoration and control reefs, as well as across monitoring periods. This indicates major structural changes and ecological enhancement as a result of the memorial reefs.

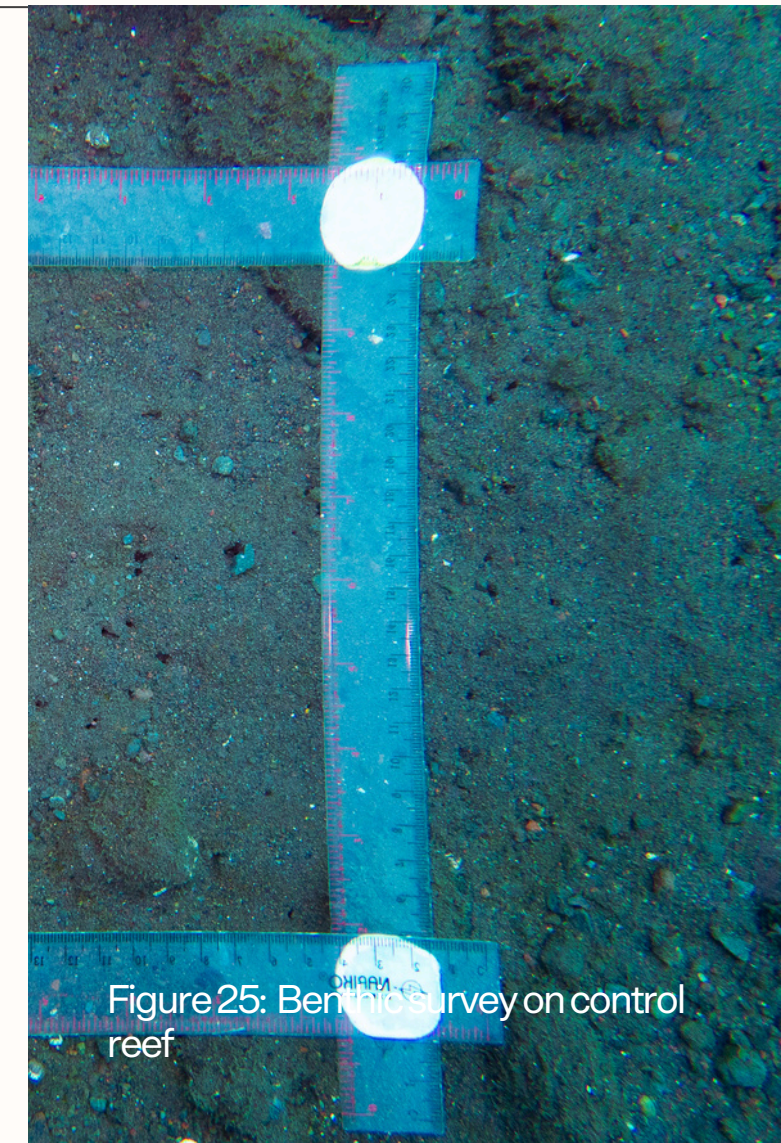


Figure 25: Benthic survey on control reef

# SUMMARY OF RESULTS

## 3. HARD CORAL AND CORALLINE ALGAE INCREASE SUBSTANTIALLY OVER 1 YEAR.

Hard coral cover rose from zero to over

# 4-5 %

within a year, while coralline algae expanded to dominate up to 45 % of benthic cover, aiding in reef formation and early habitat stabilisation.

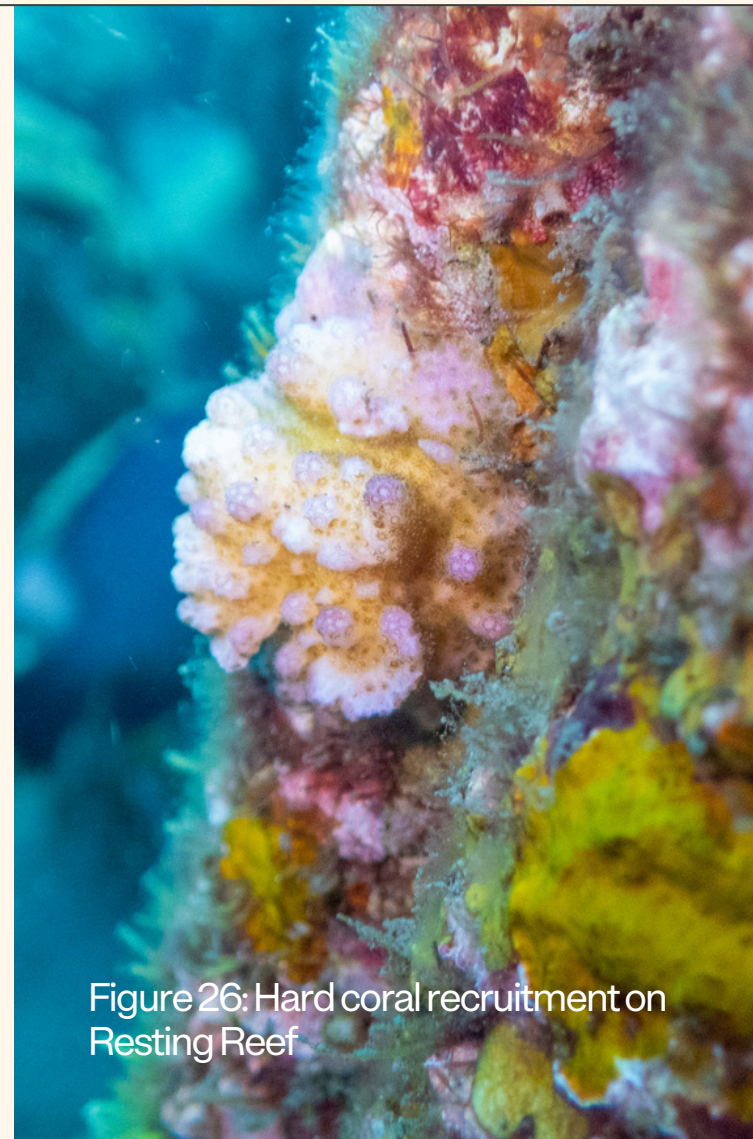


Figure 26: Hard coral recruitment on Resting Reef

## 4. MEMORIAL REEFS DRAMATICALLY INCREASED FISH BIODIVERSITY.

Memorial reefs supported up to

# 10x

more fish species than nearby control sites (Tianyar RR: 102 species vs. 6 in control; Tulamben RR: 67 vs. 16).



Figure 27: Coral grouper (Cephalopholis miniata) on Resting Reef

# SUMMARY OF RESULTS

## 5. STATISTICAL ANALYSES CONFIRM SIGNIFICANT ECOLOGICAL RECOVERY.

Species richness and abundance were significantly higher at restoration sites, and community composition showed clear differences between restored and control reefs.



Figure 28: Tunicate (*Didemnum molle*) growing on a Resting Reef.

## 6. TIANYAR RESTORATION SITE SHOWS EXCEPTIONAL RECOVERY SUCCESS.

Hosting the highest richness and abundance overall, Resting Reefs in Tianyar appeared to be progressing faster than Tulamben, suggesting unique conditions there which made it especially good for attracting and supporting fish assemblages.

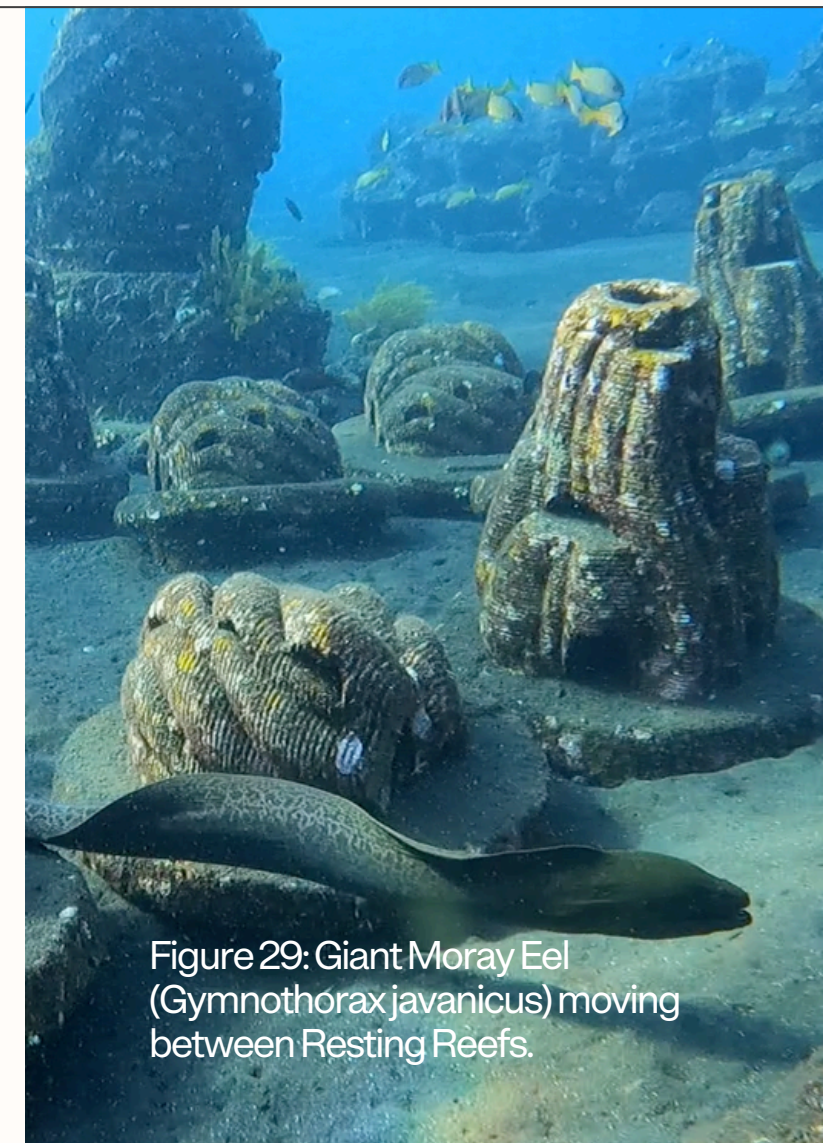


Figure 29: Giant Moray Eel (*Gymnothorax javanicus*) moving between Resting Reefs.



Figure 30: Scorpionfish (Scorpaenidae) resting on a Resting Reef.

# LIMITATIONS OF THE STUDY

There are some limitations of this monitoring which should be considered. The monitoring period so far captures only the earliest stages of ecological colonisation. Longer-term monitoring will be needed to determine how communities continue to develop, whether coral cover continues to increase, and how stable and functional these new ecosystems become over time. In addition, expanding the number of sites and replicates would help to confirm the generality of these results across different environmental settings.



Figure 31: Critically endangered Hawksbill sea turtle (*Eretmochelys imbricata*) moving between Resting Reefs

## Differences between fish communities between Tianyar and Tulamben Resting Reefs

The memorial reefs in Tianyar were found to perform substantially better than those in Tulamben in terms of fish species richness and abundance, especially when compared to their corresponding control sites. It must, however, be noted that the memorial reefs in Tianyar were placed next to an existing artificial reef that already had high fish species richness and abundance, which likely helped boost colonisation on the Resting Reef units. Meanwhile, the Tianyar control was almost empty, with very low fish assemblages. In contrast, the memorial reefs in Tulamben were placed in a much emptier area, so, unsurprisingly, fewer fish would move in. In addition, the Tulamben control site - although degraded - still had more fish than the Tianyar control site. The differences between sites make it difficult to directly compare results: the Tianyar Resting Reef units may look more successful simply because they were placed near an already healthy reef (with a very degraded control site), while the Tulamben memorial reefs may appear less successful because they were placed in a relatively empty area (with a slightly less degraded control site). These differences, which were unavoidable from an experimental perspective, make direct comparisons between the two sites somewhat unfair. However, testing the memorial reefs in contrasting environmental and ecological conditions was still beneficial and valuable, as it provided stronger evidence that the design can enhance marine life across a range of starting points.

## Difference between benthic composition between Tianyar and Tulamben Resting Reefs

As shown by Figure 22, hard coral cover was higher in Tianyar (4.7%) compared with Tulamben (2.9%), representing a 39% lower hard-coral cover at Tulamben. Initially, one may conclude that structures without ashes (in Tianyar) perform better than those with ash (Tulamben). However, the differences in benthic composition between Tianyar and Tulamben at 12 months likely reflect both restoration processes and natural environmental variability. The slightly higher hard coral cover at Tianyar may indicate stronger coral recruitment pressure during the monitoring period. Coral larval supply can vary substantially across small spatial scales due to hydrodynamics, proximity to spawning adult colonies, and current-driven larval delivery. If Tianyar experienced higher larval input or more favourable settlement conditions, this could explain the elevated coral cover observed. Conversely, Tulamben showed higher turf-algal cover, suggesting that localised competition, nutrient conditions, or grazing pressure may have constrained coral settlement or early survivorship. These differences reinforce that restoration outcomes depend not only on the performance of Resting Reef structures (and whether they contain ashes) but also on the ecological context in which they are deployed.

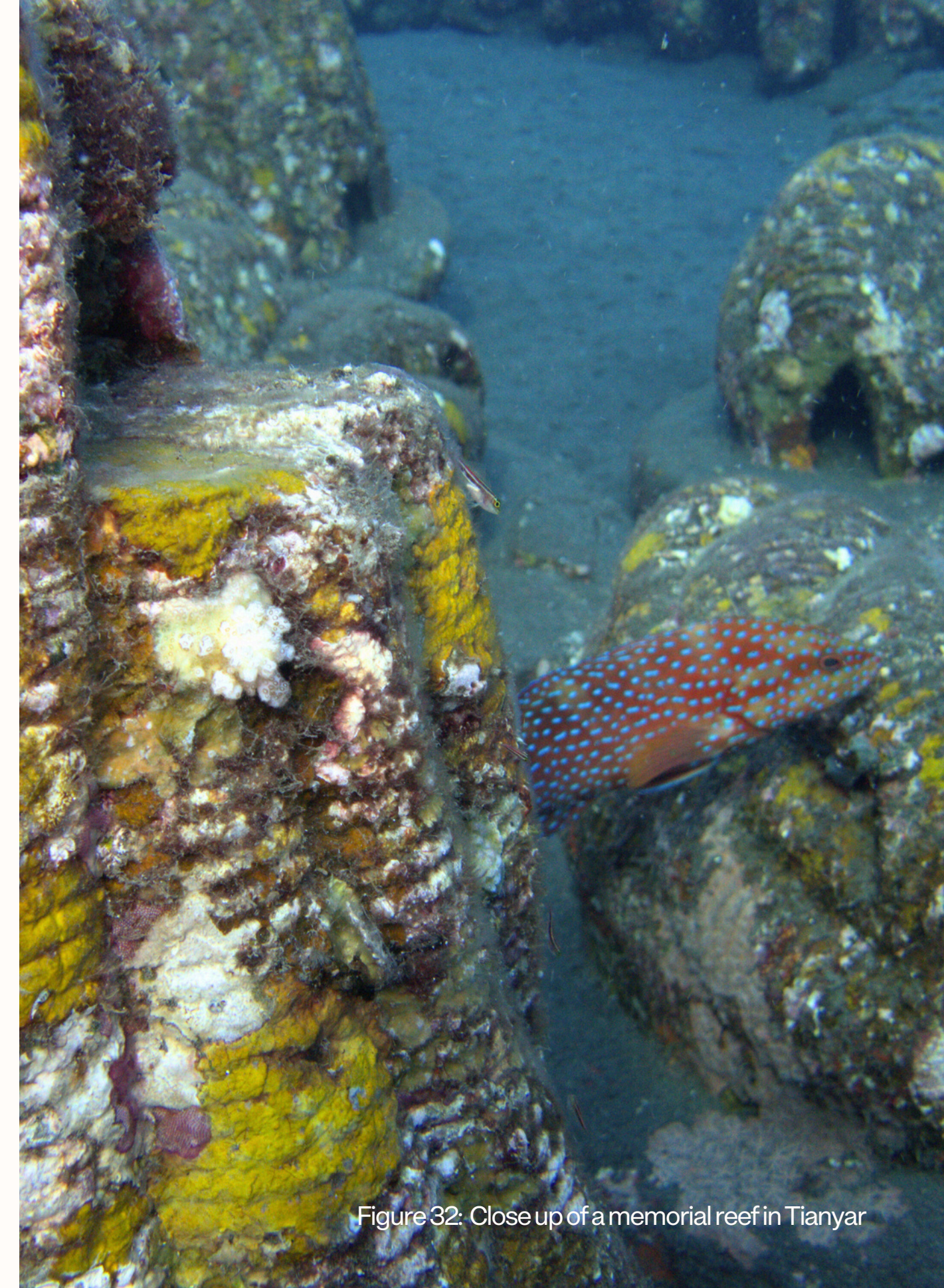


Figure 32: Close up of a memorial reef in Tianyar

Importantly, the results of this pilot found no evidence that incorporating cremation ash into the structural mix compromised the durability of the memorial reefs over the monitoring period. While ecological outcomes differed slightly between Tianyar and Tulamben- likely reflecting natural variation in larval supply and local environmental conditions - the results showed that ash-integrated memorial reefs still supported diverse benthic and fish communities, and remained structurally durable over the monitoring period. Overall, the findings demonstrate that well-formulated and carefully designed memorial reef units can provide meaningful remembrance for families while delivering tangible ecological benefits.



Figure 33: Production of Resting Reef memorial reefs in Tulamben, which incorporate cremated ashes.



Figure 34: Following local traditions, all Resting Reef memorial reefs underwent a 'blessing' ceremony before being deployed in Tulamben.

# SOCIOECONOMIC BENEFITS

Although this assessment focused primarily on the ecological outcomes of the memorial reefs, several potential socioeconomic benefits were also observed during and after implementation. While no formal social or economic survey was conducted, the project did generate direct employment opportunities, including hiring five local workers to construct and deploy the reef units. Each time Resting Reef deploys memorial reefs, a community donation is provided locally, supporting community development initiatives alongside cultural and spiritual activities. In addition, the restored reef site is now being visited by tourists, creating a new attraction that local dive centres and snorkel guides can incorporate into their tours. As a result, the project may be contributing to increased livelihood opportunities and supplemental income for community members involved in tourism activities. These early indications suggest that Resting Reefs have the potential not only to enhance marine ecosystems but also to provide meaningful economic and social value to surrounding coastal communities.

# CONCLUSION

Within a year of deployment, the Resting Reef memorial reef units in North Bali have demonstrated strong ecological performance. Benthic diversity on the units greatly exceeded that of nearby degraded control sites, hard coral and coralline algae cover increased substantially, and fish communities became dramatically richer and more abundant. These early results indicate that Resting Reef units provide a high-quality and durable habitat, support rapid ecological recovery, and offer a promising tool for community-driven marine restoration in Bali and beyond. The successful performance of ash-integrated units suggests that it is possible to deliver a meaningful memorial service that also contributes positively to reef restoration. Continued monitoring and refinement of the design, materials, and deployment strategies will further enhance the ecological benefits of Resting Reef projects and strengthen the evidence base for their use in future restoration initiatives.



Figure 35: Production of Resting Reef memorial reefs in Tianyar

# ACKNOWLEDGEMENTS



Figure 36: The team next to the plaque with sponsor names in Tianyar.

Resting Reef would like to thank our incredible team for making this pilot a reality. To Wei Zhang for leading the design, engineering, and development of our reefs, and to Dr. Zach Boakes for introducing us to the community in Tianyar and his scientific contributions to Resting Reef's monitoring process.

We are grateful to Tianyar's and Tulamben's local communities for their openness, teachings, and collaboration, which have been vital to this project's success. Especially, thank you to Pak Nyoman Degeng for introducing the Resting Reef concept to the local stakeholders and leading our pilot in Tulamben.

It is important to highlight the support our interns have provided over the past year, and a special shoutout to Pat, Jacob, and Sianna, who joined us on-site in Bali. We would also like to acknowledge our collaborators in design, production, and technical expertise who played an essential role: CubeX Industries, Exo Engineering, and Watson Farm Equine.

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Figure 37: Deployment of Resting Reefs in Tianyar